High-p_T Identified v_2 measurement in Au+Au collisions at 200 GeV

Masahiro Konno
(Univ. of Tsukuba)

Outline

Physics motivation:

- Hadron production at intermediate p_T
- Elliptic Flow

Technical aspects (with results):

- How to determine Reaction Plane
- How to identify particles (PID)
  - + TOF
  - + Aerogel, MRPC-TOF
  - + pi0, photon

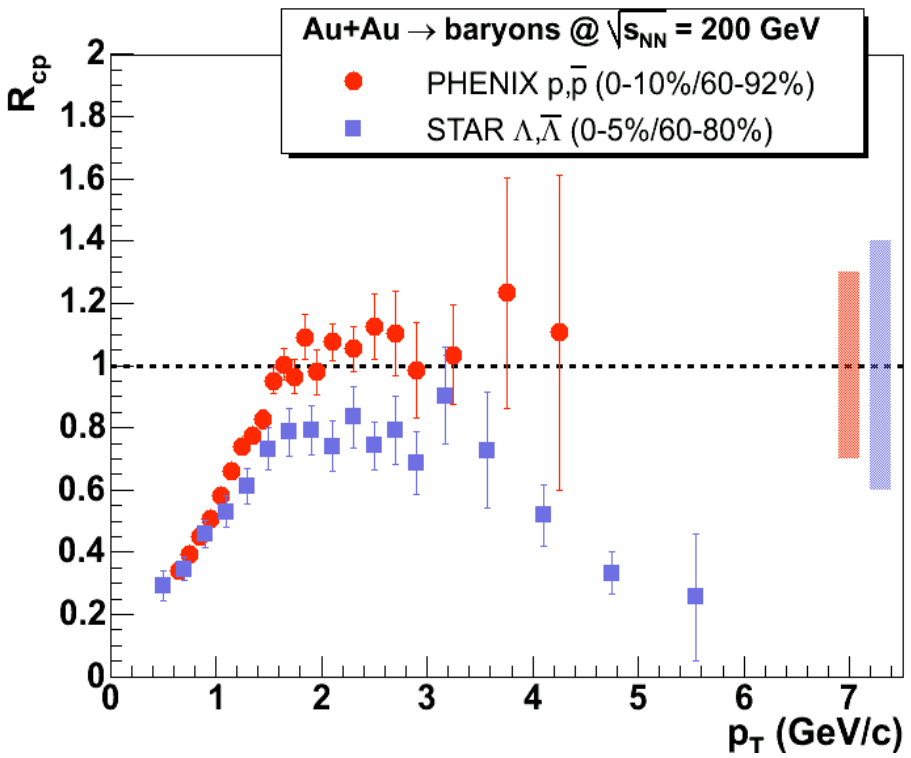
Summary

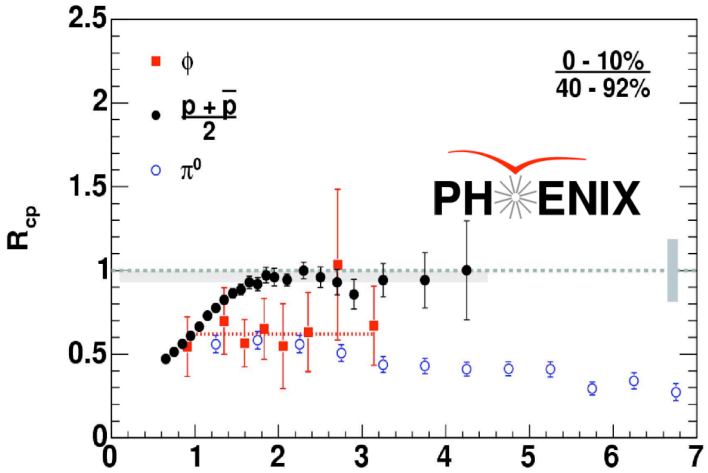
Hadron production at intermediate p_T : Baryons vs. Mesons

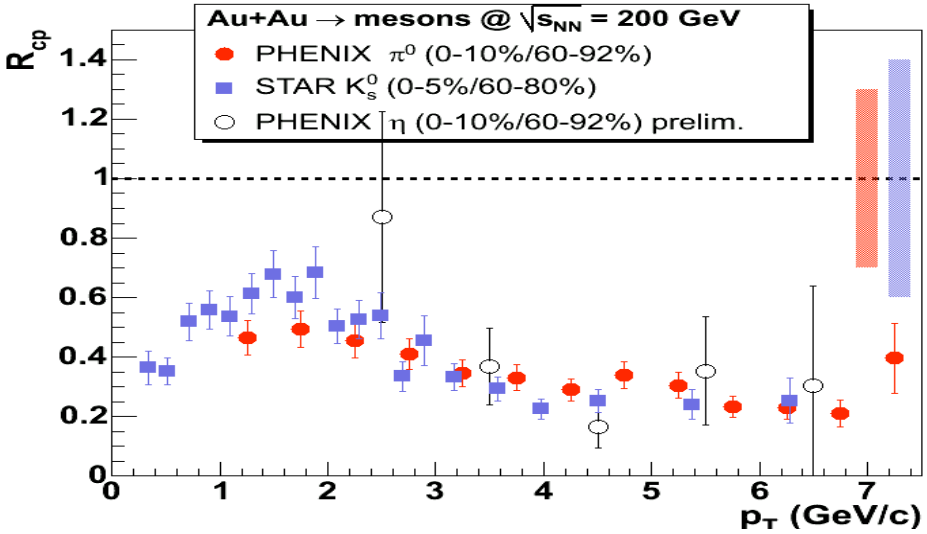
Unsuppressed Baryon Production

(1.5 - 4 GeV/c)

PRL91:172301(2003), nucl-ex/0306007







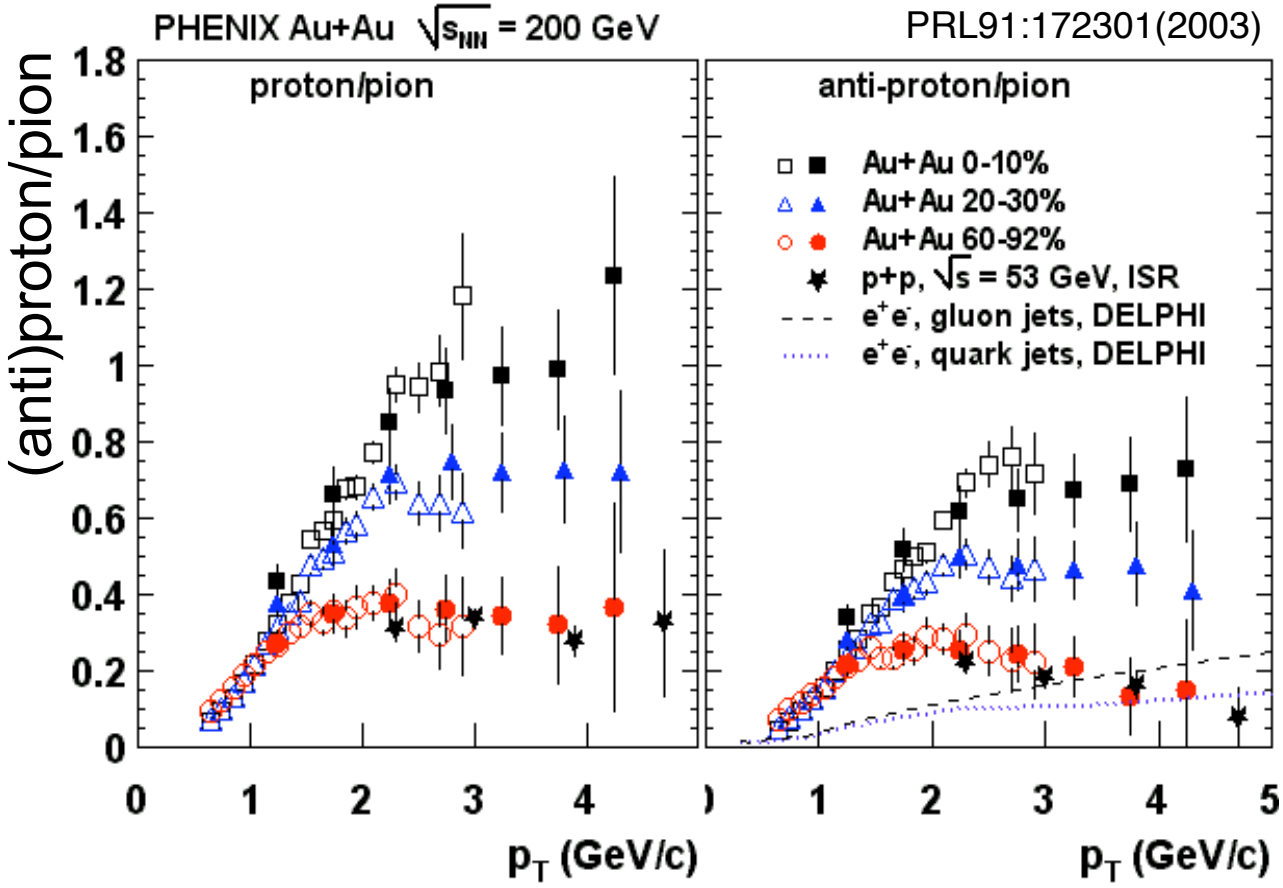
Baryons: p, $\bar{p}$, Λ, $\bar{\Lambda}$ **NOT** (or much less) suppressed in central Au+Au.

Mesons: p^0, K^0_s, η, phi equally suppressed.

- Inclusive charged hadrons suppressed by a factor of 4~5 at p_T>5 GeV/c.

- Particle-type dependent nuclear modification at intermediate p_T.

Large Baryon/Meson Ratios



- Central Au+Au:
  p/π ~ 0.8 (at p_T = 2-4 GeV/c)
  at variance with perturbative production mechanisms (favour lightest mesons).

-Peripheral Au+Au:
  p/π ~ 0.2 as found in p+p & e+e- jet fragmentation.

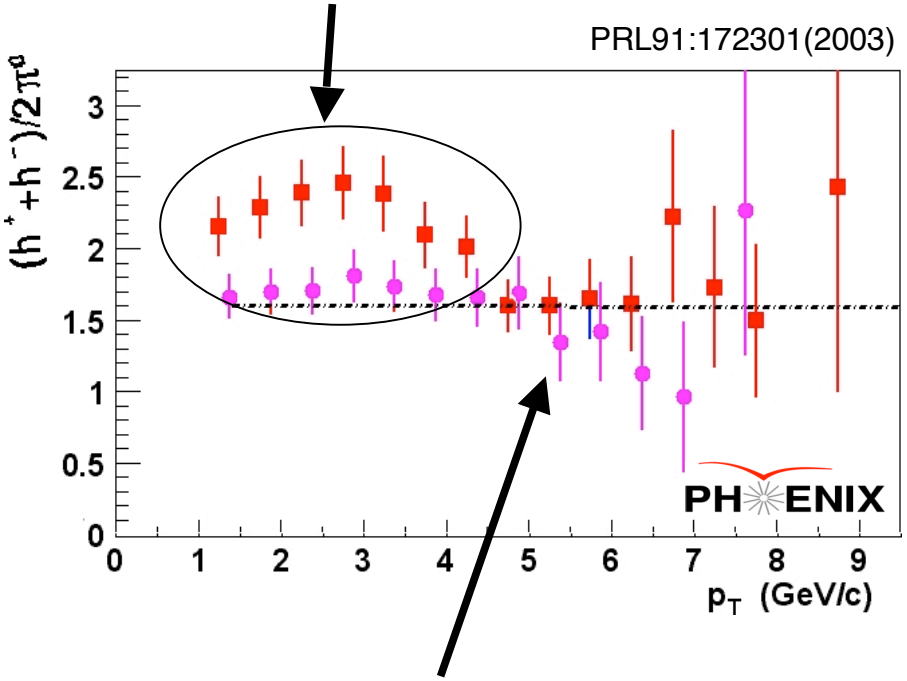
- For p_T>2 GeV, protons are as abundant as pions !

- Particle composition inconsistent with known fragmentation functions.

- Additional production mechanism for baryons in the intermediate p_T range.

Hadron/Meson Ratio

Au+Au (central): hadron/meson ~ 2.5 at p_T = 1 - 4 GeV/c (inconsistent w/ known fragmentation functions).



Baryon enhancement limited to p_T < 5 GeV/c ($h^{\pm}/\pi$ ~ 1.6 in p+p collisions): $h^{\pm}$, π^0 equally suppressed.

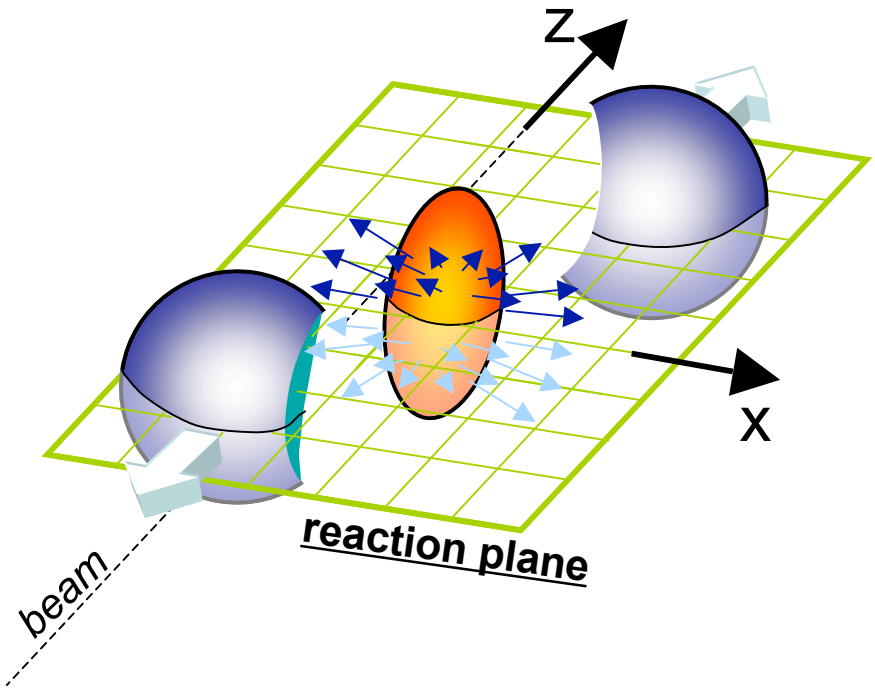
Elliptic Flow : Baryons vs. Mesons

Elliptic Flow

$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos 2(\phi - \Phi_{\mathrm{RP}})$$

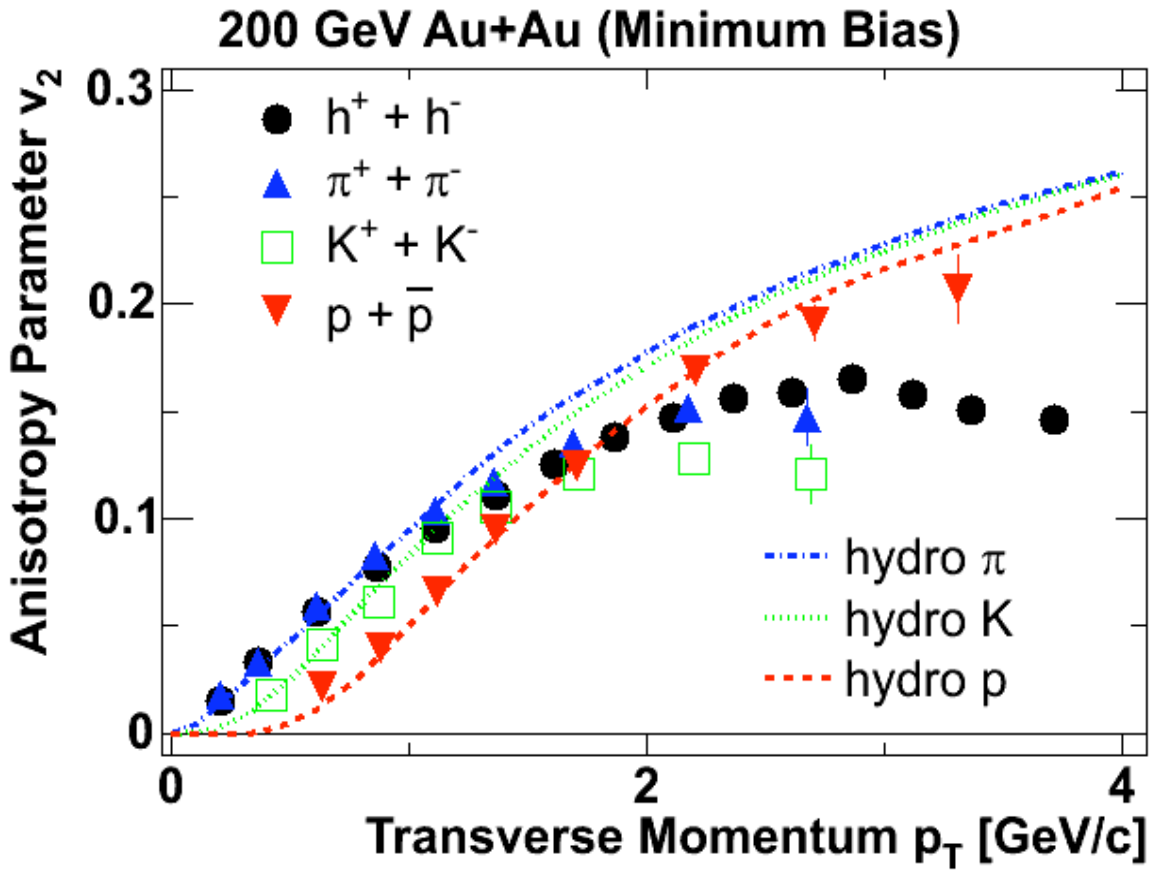
v_2 : 2nd Fourier coefficient of dN/dϕ
ϕ : Azimuthal angle (w.r.t reaction plane)

- Easily measure anisotropy for identified particles.
- Should determine reaction plane experimentally.
- Suffer resolution of reaction plane (smearing).



A sensitive probe in the early stage of relativistic heavy ion collisions:
- Pressure gradient build up elliptic flow.
- Initial anisotropy in x-space in non-central collisions translates into final anisotropy in p-space.

v_2 of baryons and mesons



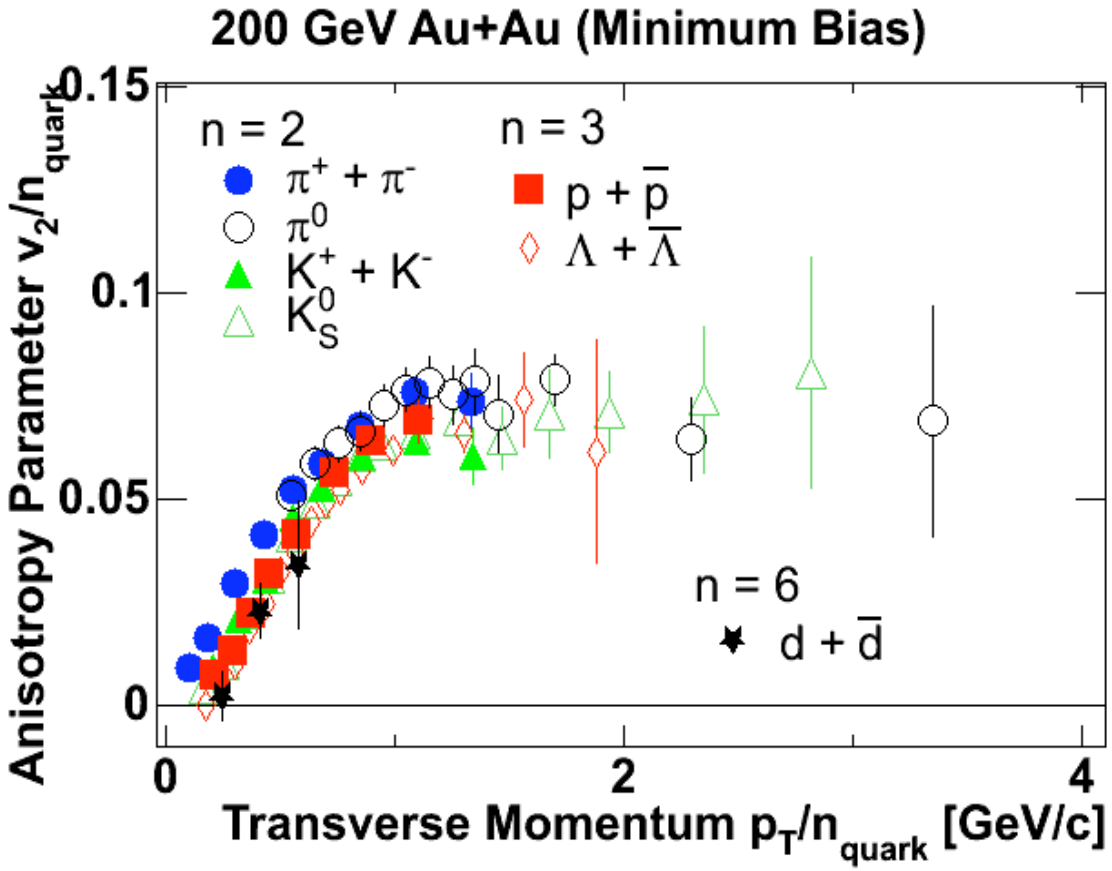
- At low pt, hydro works well.
- Mass dependence of v_2 consistent w/ hydrodynamics.

$v_2^{meson} > v_2^{baryon}$ at low p_T
$v_2^{meson} \approx v_2^{baryon}$ at $p_T \approx$ 2 GeV/c
$v_2^{meson} < v_2^{baryon}$ at higher p_T

PHENIX: Phys. Rev. Lett. 91 182301 (2003)

- Different v_2 saturation values for mesons and baryons.
- Enhanced baryonic elliptic flow observed.

Quark Number Scaling



π, K, p (PHENIX) :
Phys. Rev. Lett. 91 182301 (2003)
K^0_S, Λ (STAR) :
Phys. Rev. Lett. 92 052302 (2004)
π^0 (PHENIX) : nucl-ex/0404014
Deuteron : PHENIX PRELIMINARY

- **Quark number scaling works.**
- **Expected from recombination.**
- **$v_2^s \sim v_2^{u,d} \sim 7\%$**
- **Indicate partonic collectivity.**

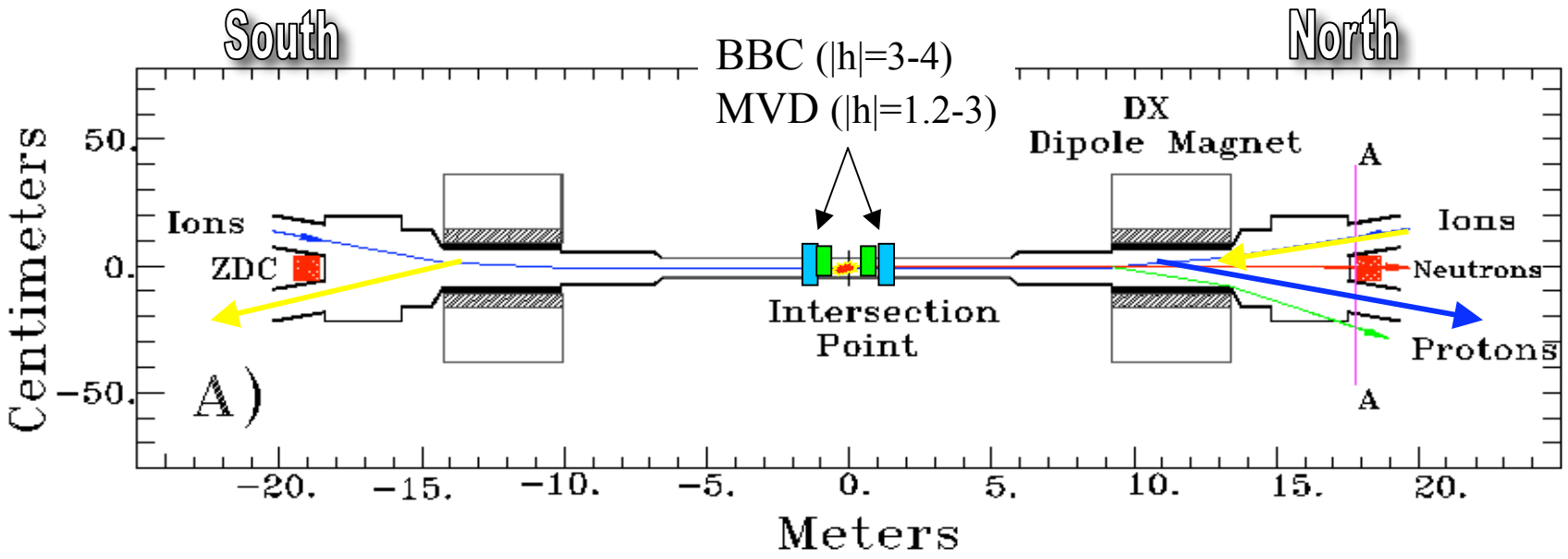
Outline

Technical aspects (with results):

- How to determine Reaction Plane
- How to identify particles (PID)
  - + TOF
  - + Aerogel, MRPC-TOF
  - + π^0, γ

How to measure Event Anisotropy experimentally (in case of PHENIX)

Reaction Plane Detectors: BBC,SMD,MVD



Beam-Beam Counter (BBC)

|h|=3~4

64pmts in each BBC

Detect charged particles

Shower-Max Detector (SMD)

Inside ZDC

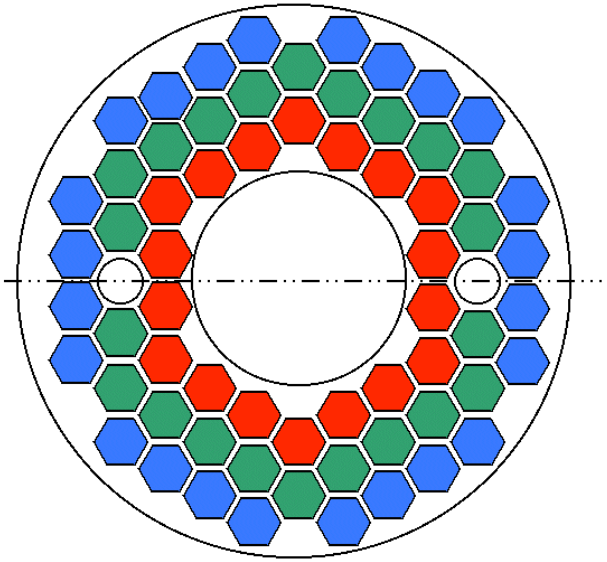
Detect spectator-neutron energy

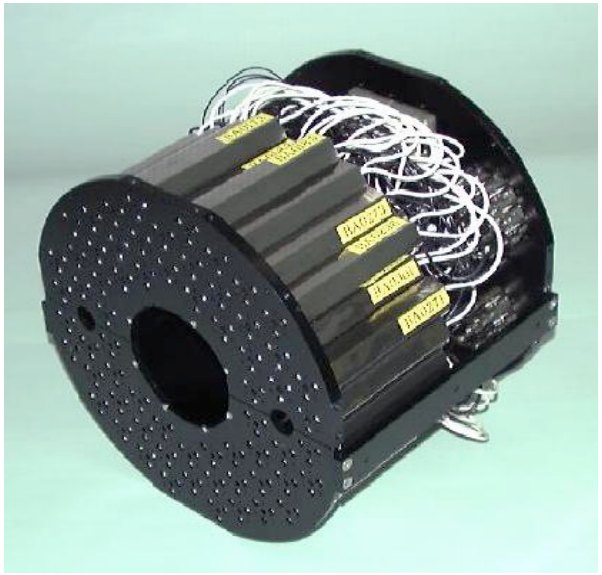
Measure beam position

Multiplicity Vertex Detector (MVD)

Silicon pad detector at endcaps

BBC





Beam-Beam Counter (BBC)

|h|=3~4

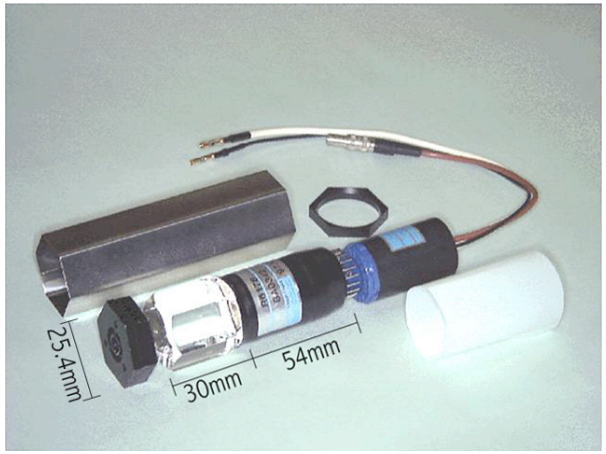
Consists of 64 pmts in each

Detect charged particles

MIP calibration for each pmt

Ring gain correction

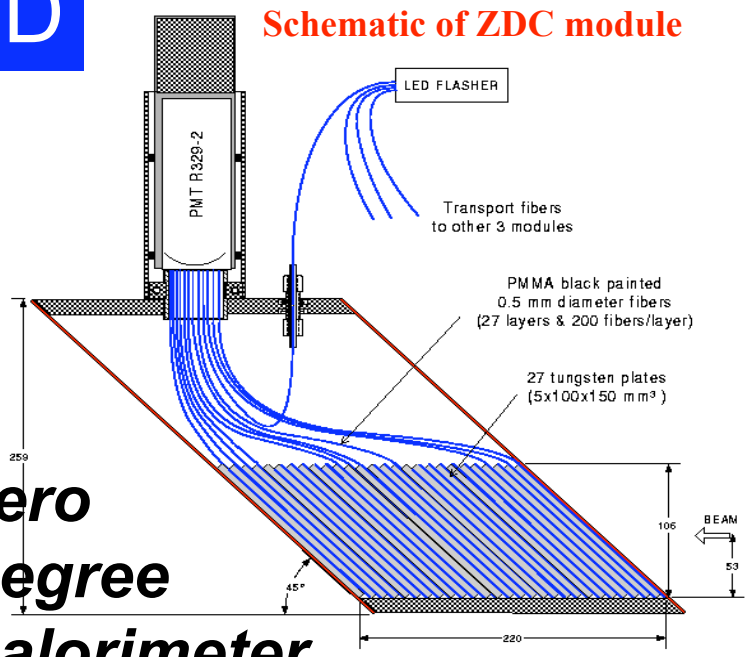
Removing 4 special pmts



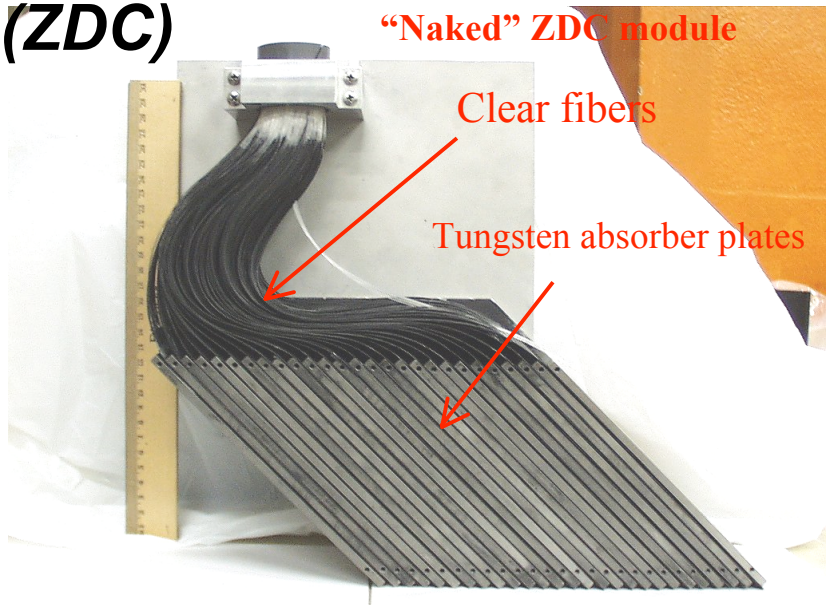
SMD

Zero Degree Calorimeter (ZDC)

Schematic of ZDC module



"Naked" ZDC module

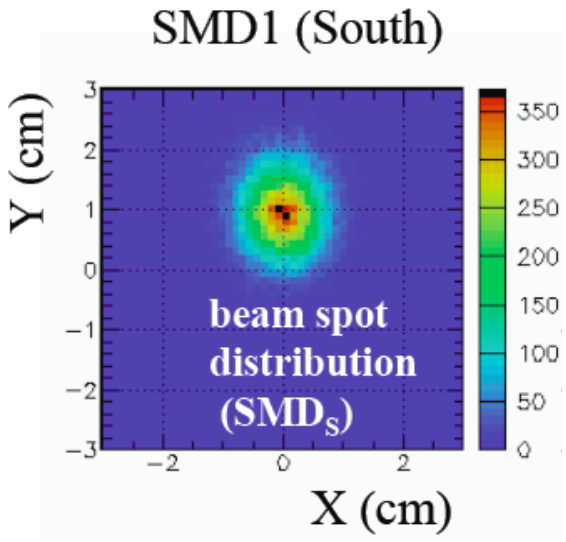


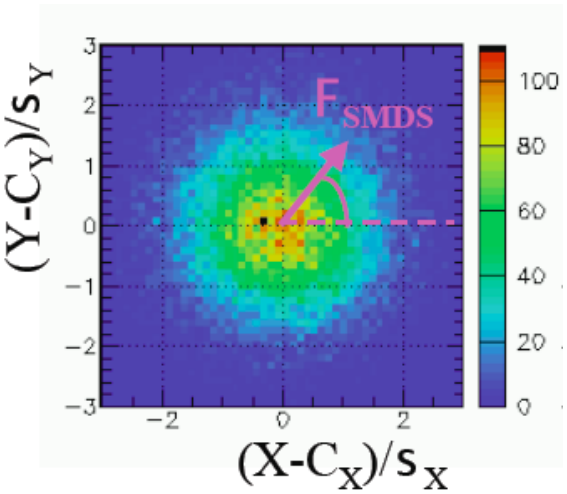
Shower Maximum Detector (SMD)

RP Determination

$$Q_x = \sum_i^N w_i \cos(n\phi_i)$$
$$Q_y = \sum_i^N w_i \sin(n\phi_i)$$
$$Q_w = \sum_i^N w_i$$
$$Q_x' = \frac{Q_x - \langle Q_x \rangle}{\sigma_x}$$
$$Q_y' = \frac{Q_y - \langle Q_y \rangle}{\sigma_y}$$
$$\Psi_{obs} = \tan^{-1}\left(\frac{Q_y'}{Q_x'}\right)$$

N : number of particles in an event
f : azimuthal angle of detected particles
w : weight (p_T, multiplicity etc)
n : 1=directed, 2=elliptic

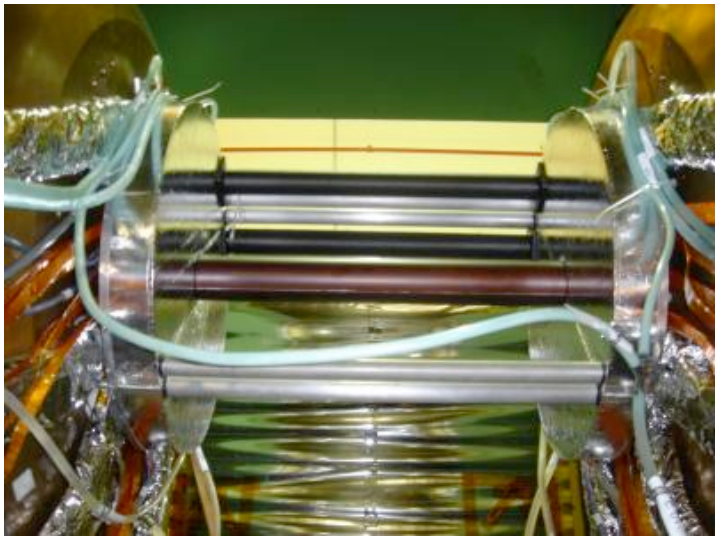




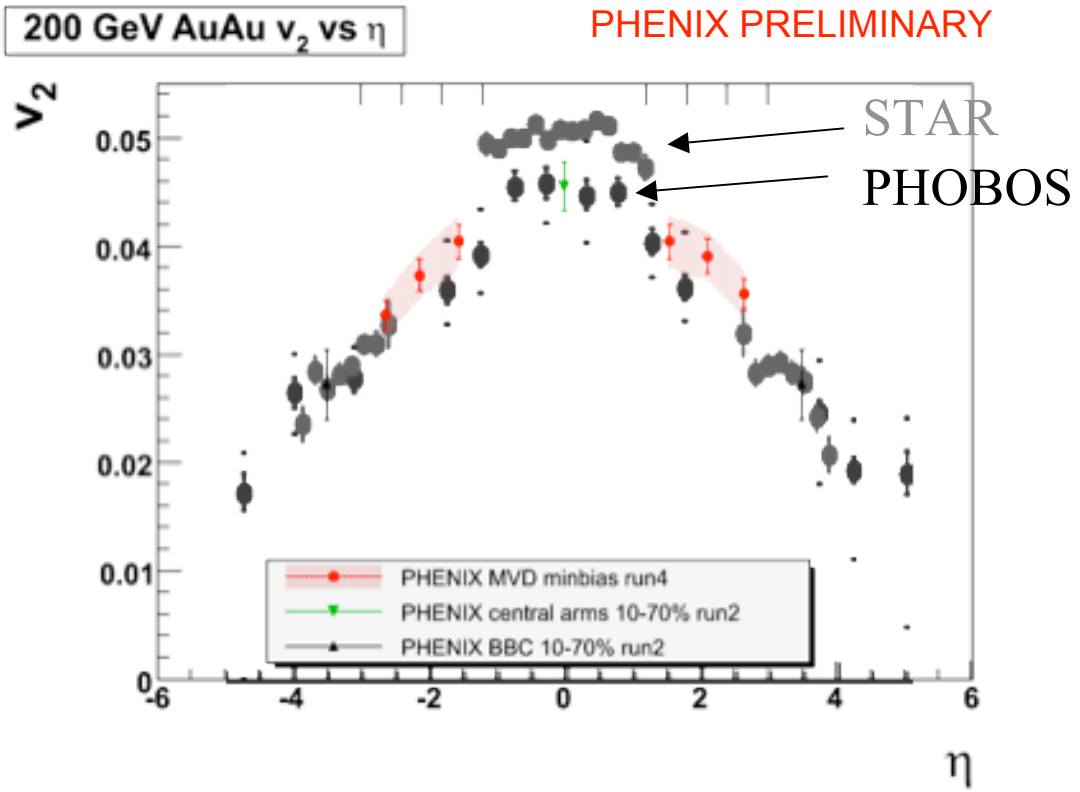
1. Average sin/cos shift correction
2. Normalized sum x/y distribution correction
3. Conventional flattering (shifting angle) correction

$$\Psi = \Psi_{obs} + \Delta\Psi$$
$$\Delta\Psi = \sum_k (A_k \cos(2k\Psi_{obs}) + B_k \sin(2k\Psi_{obs}))$$
$$A_k = -\frac{2}{k}\langle \sin(2k\Psi_{obs}) \rangle$$
$$B_k = \frac{2}{k}\langle \cos(2k\Psi_{obs}) \rangle$$

MVD (Run4)

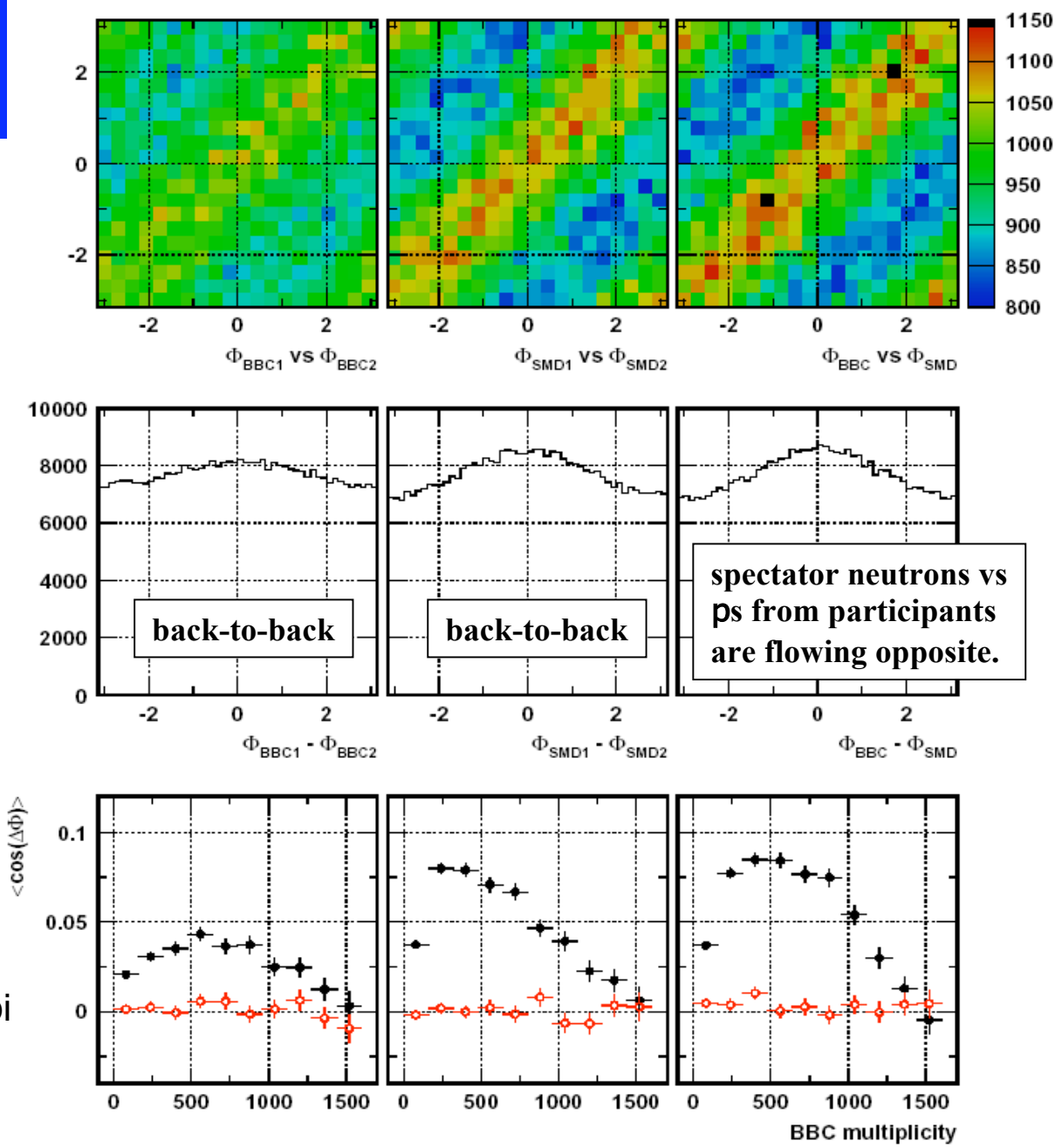


Endcap: Silicon Pad detector
(144 azimuthal and 21 radial segments)



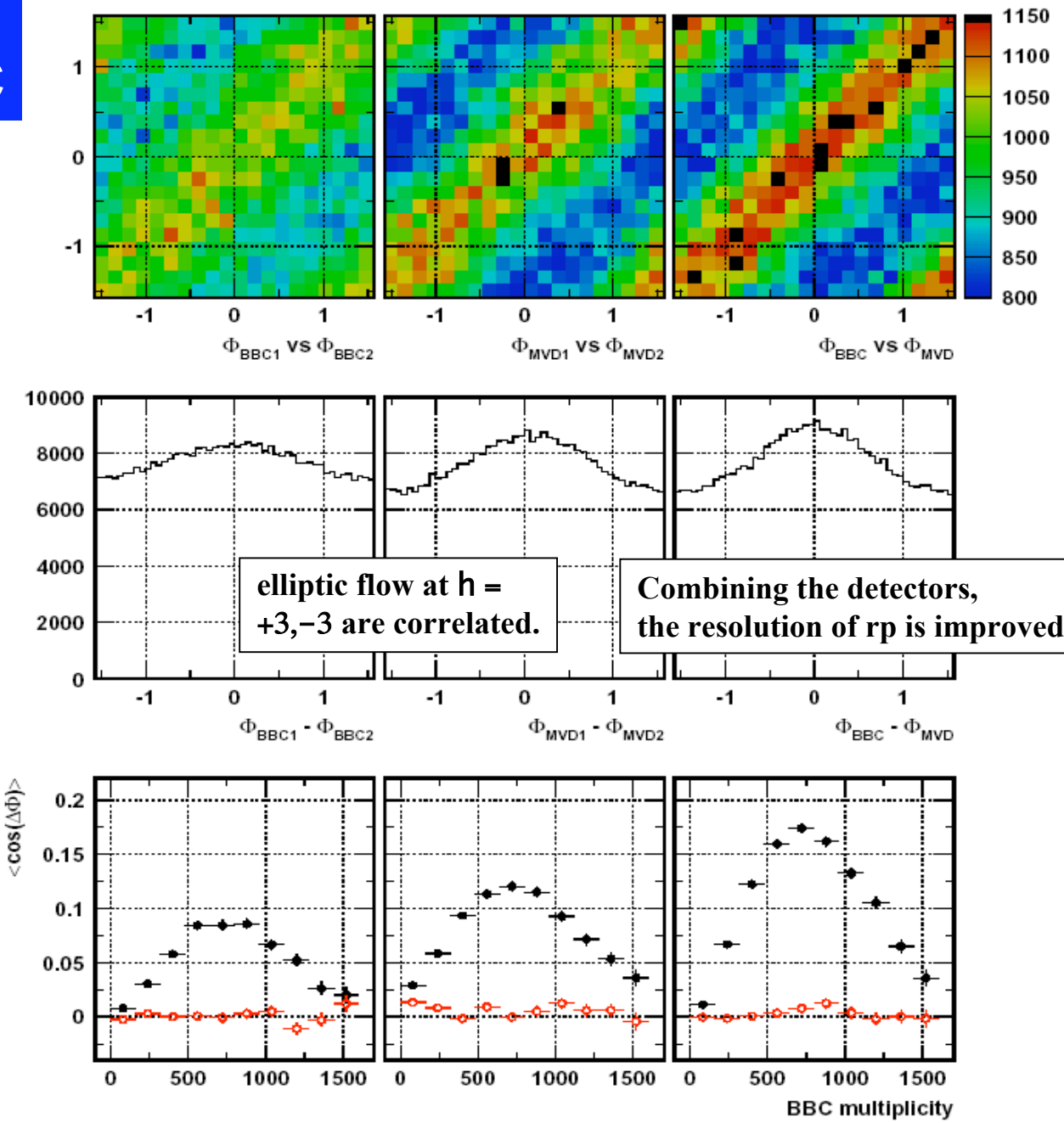
- Measurement of v_2 at MVD ($1.2 < |\eta| < 3$).
- Consistent with the previous results at PHOBOS/STAR.

SMD 1st harm RP compared with BBC



The vertical is subtracted by pi to see the correlation easily.

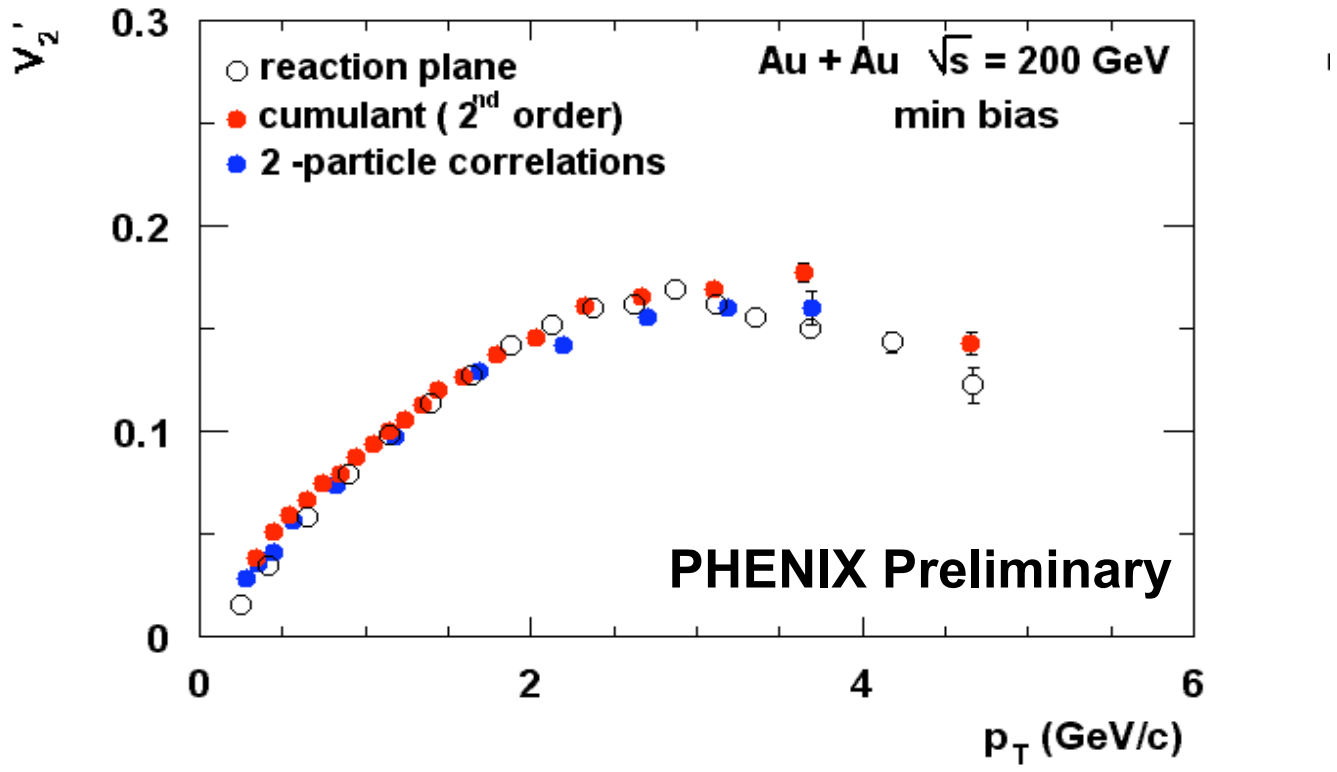
MVD 2nd harm RP compared with BBC



elliptic flow at h = +3,−3 are correlated.

Combining the detectors, the resolution of rp is improved.

v_2 vs. p_T (charged particle)

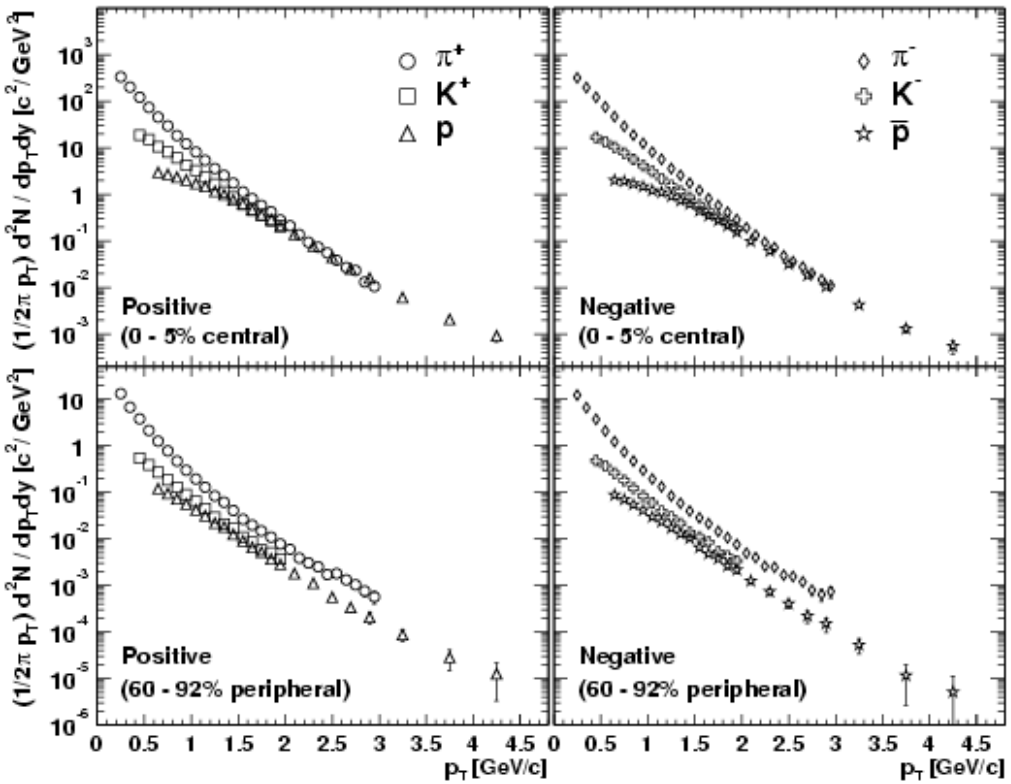


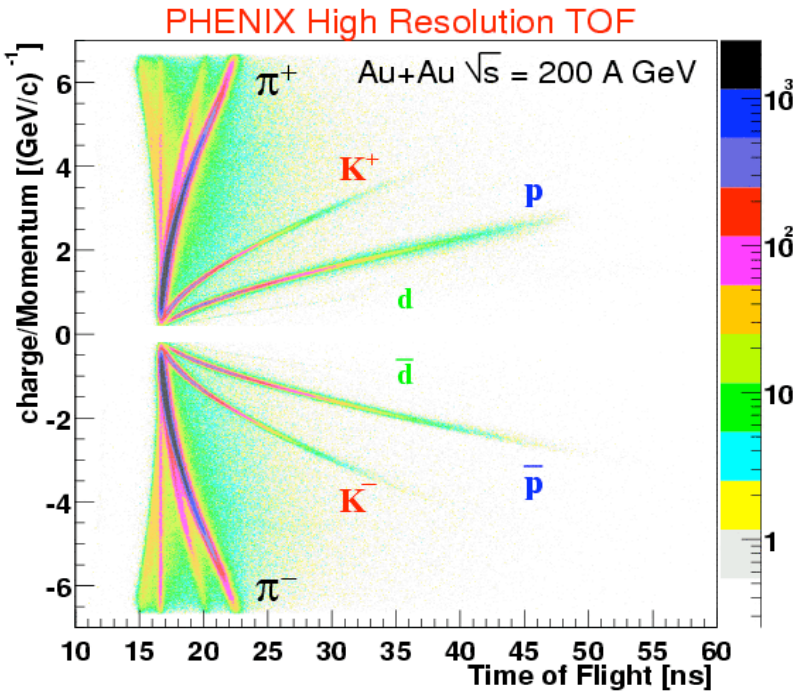
- v_2 (reaction plane) does have less non-flow because of the h gap.
- Non-flow components are removed
  in v_2 (2-particle correlation) and v_2 (2^{nd} cumulant).

How to identify particles (PID)

Time-of-Flight

PHENIX: PRC 69 034909 (2004)

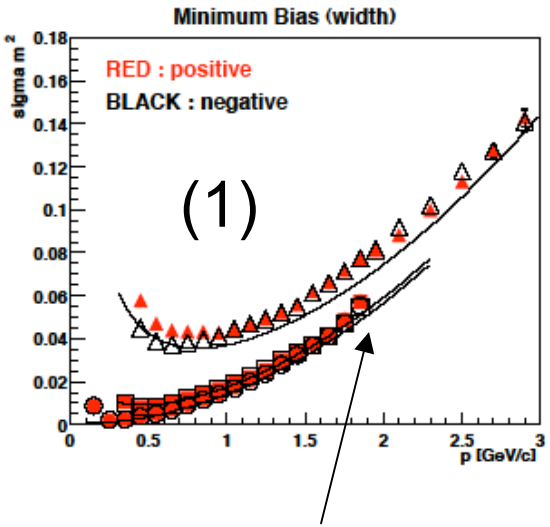


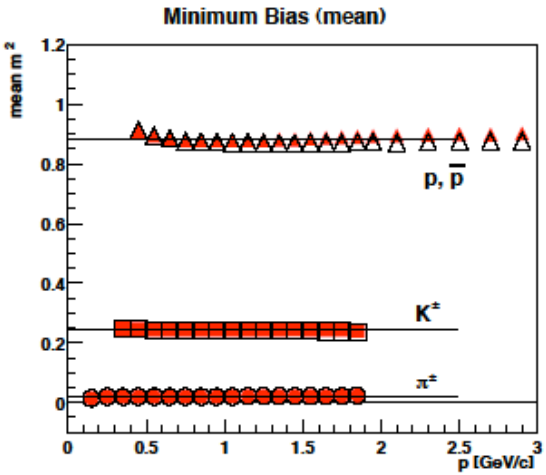


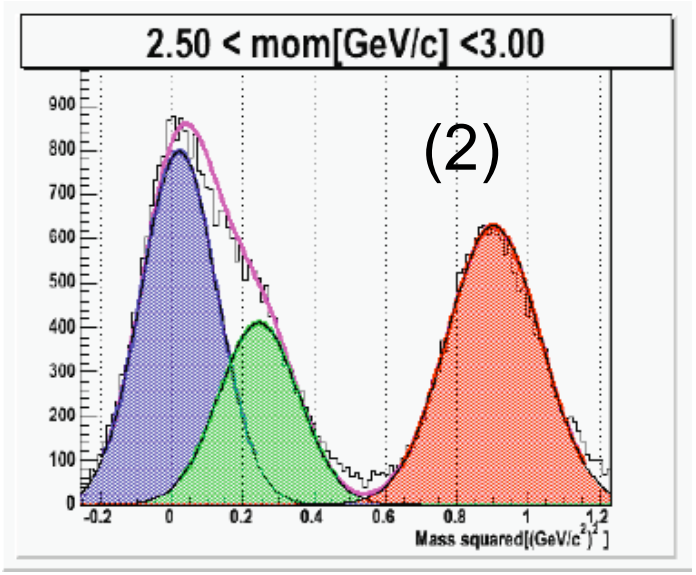
- Identify charged particles:
  - π (3 GeV/c)
  - K (2 GeV/c)
  - p (4 GeV/c)

- Many Physics Results

Extension method (TOF)





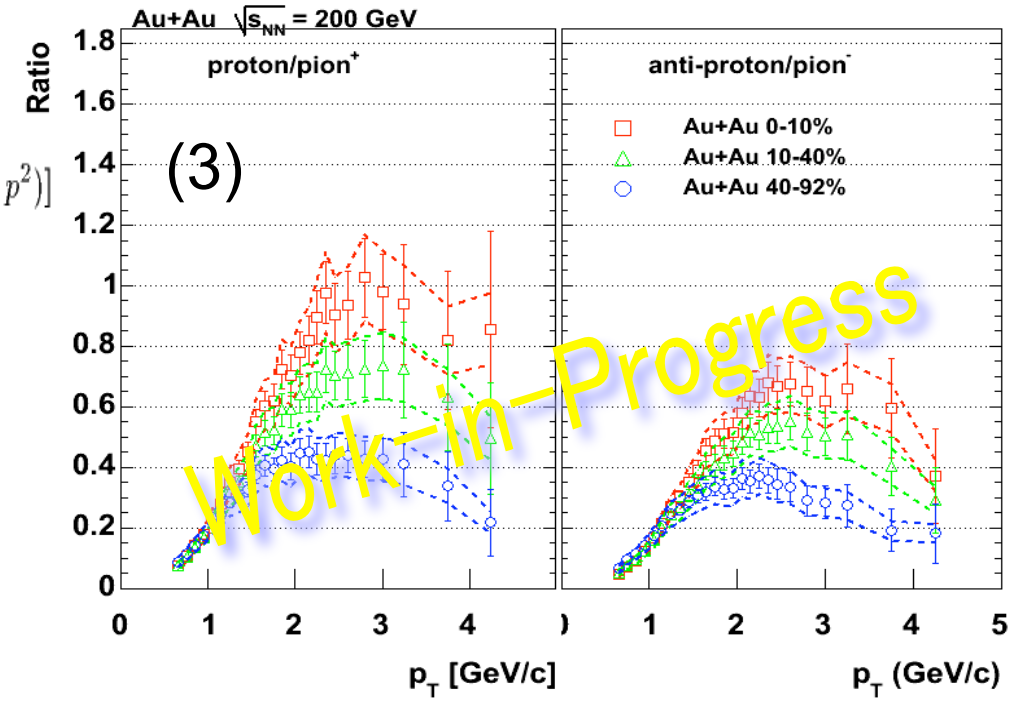


(1) The width as a function of p is parameterized:

$$\sigma^2_{m^2}(p) = \frac{\sigma^2_\alpha}{K^2}(4m^4p^2) + \frac{\sigma^2_{ms}}{K^2}\left[4m^4\left(1+\frac{m^2}{p^2}\right)\right] + \frac{\sigma^2_{TOF}\,c^2}{L^2}[4p^2(m^2+p^2)]$$

(2) Multiple gaussian function fitting (free parameters: 3 heights).

(3) Particle yield obtained for π, K, p.



PHENIX High-p_T PID Upgrade

Aerogel & MRPC-TOF

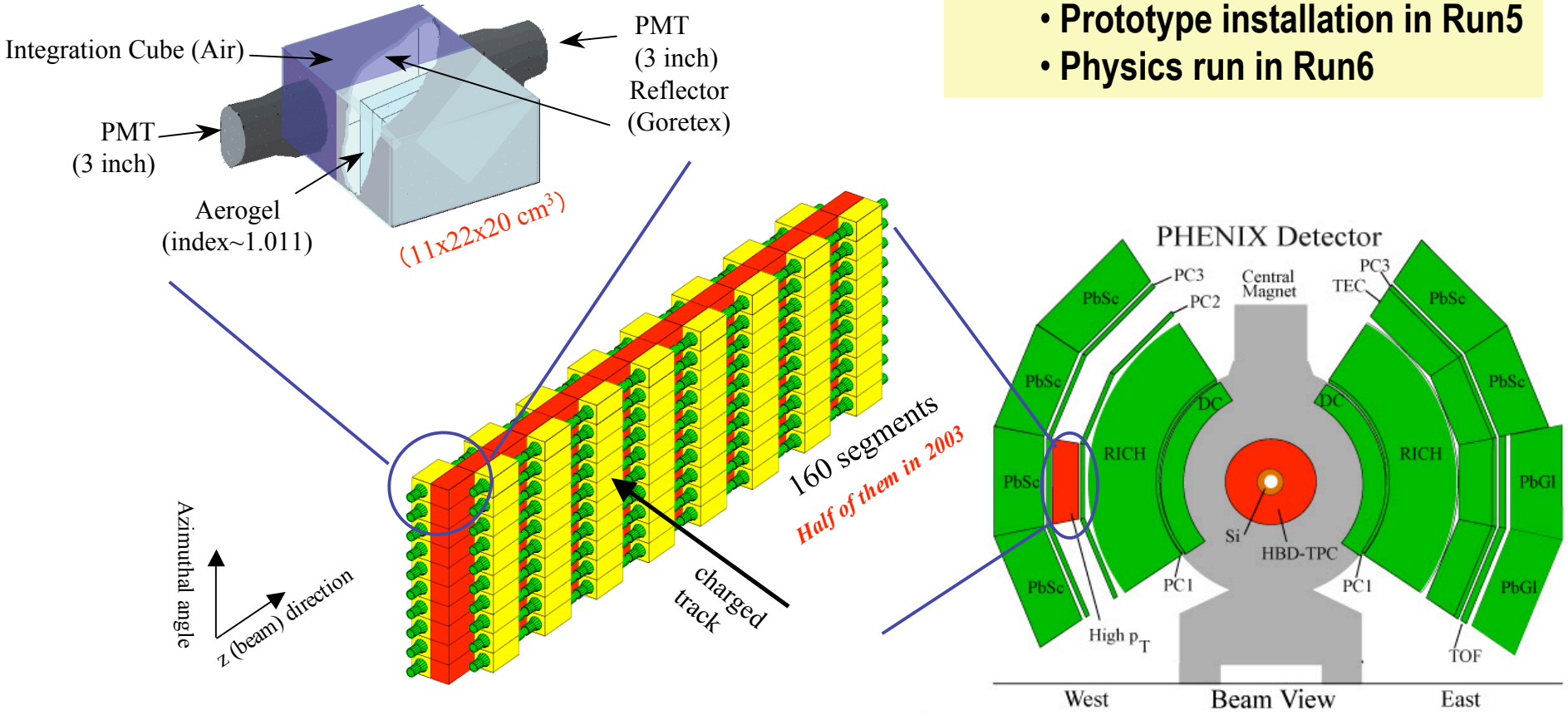
- Enhancement of Charged Hadron PID Capability.
- Together with the Aerogel, TOF and RICH, we can extend the PID beyond p_T = 5 GeV/c.

AEROGEL:

- **Installation (Run4-, Full Run5)**

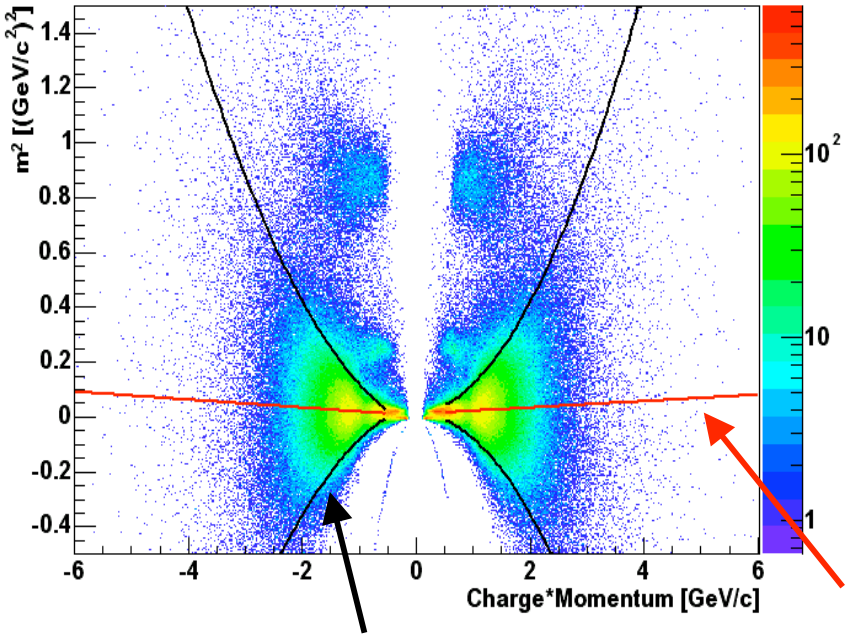
MRPC-TOF:

- **Prototype installation in Run5**
- **Physics run in Run6**



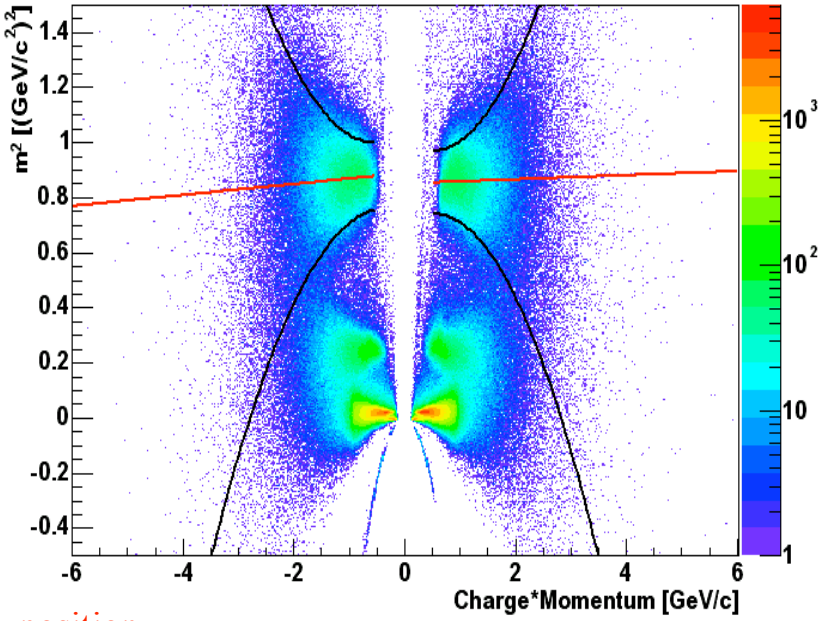
PID Plot with Aerogel

Aerogel Required ($N_{p.e.}$>3 in each PMT)



experimental resolution (2-sigma) line

Aerogel Veto ($N_{p.e.}$<1 in each PMT)



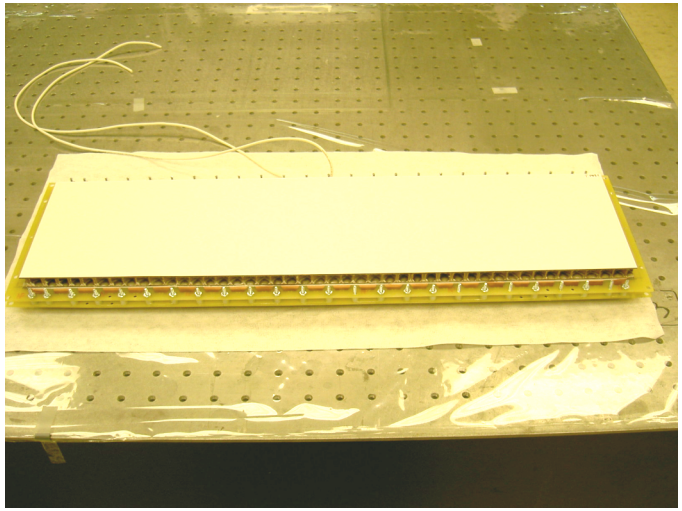
Peak position
(calibration is not perfect yet)

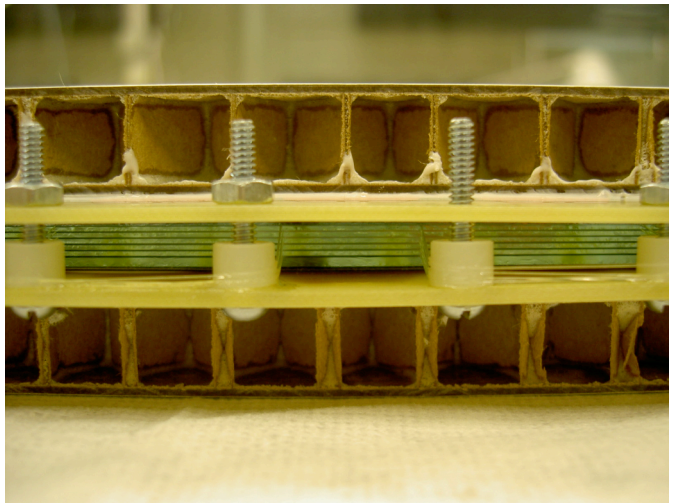
With(without) requiring Cherenkov light associated to the track

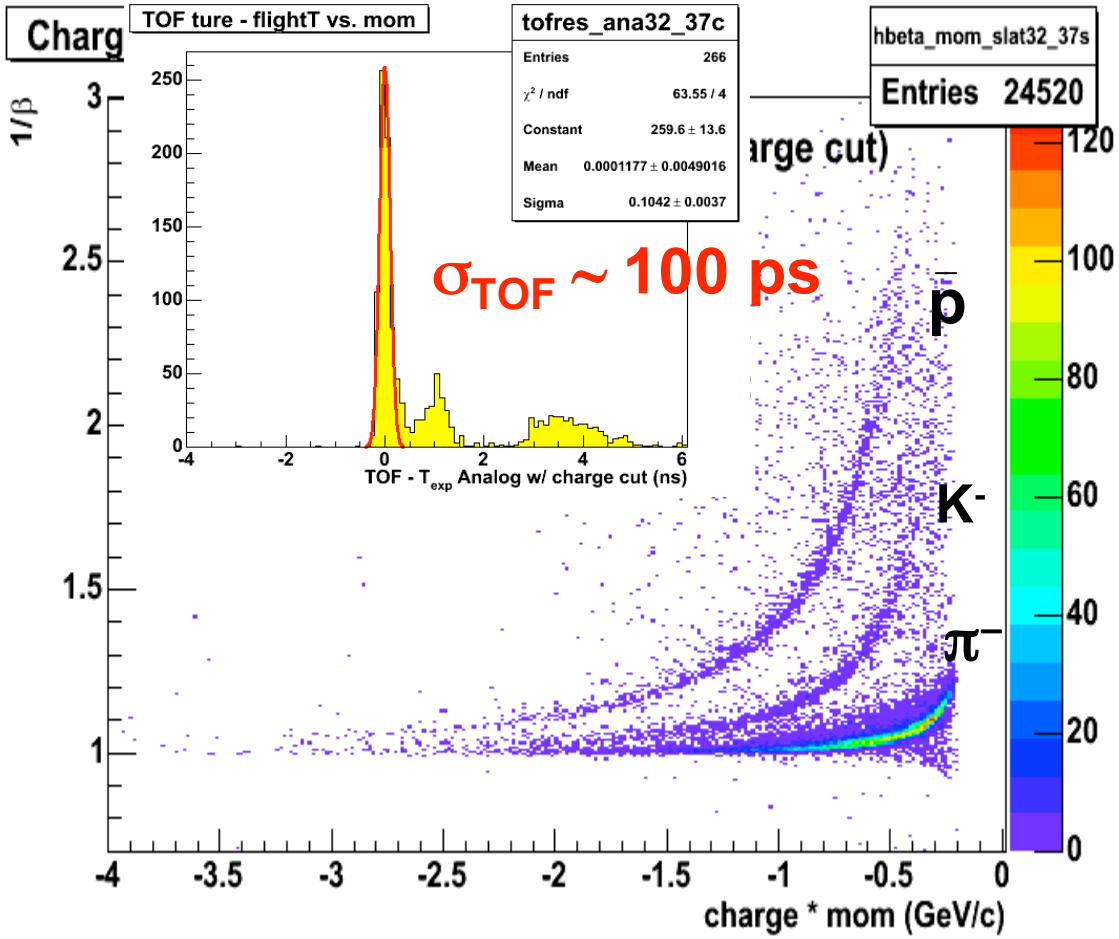
- We can see pion enhancement (rejection).
- It is functional to study intermediate p_T range.

MRPC-TOF

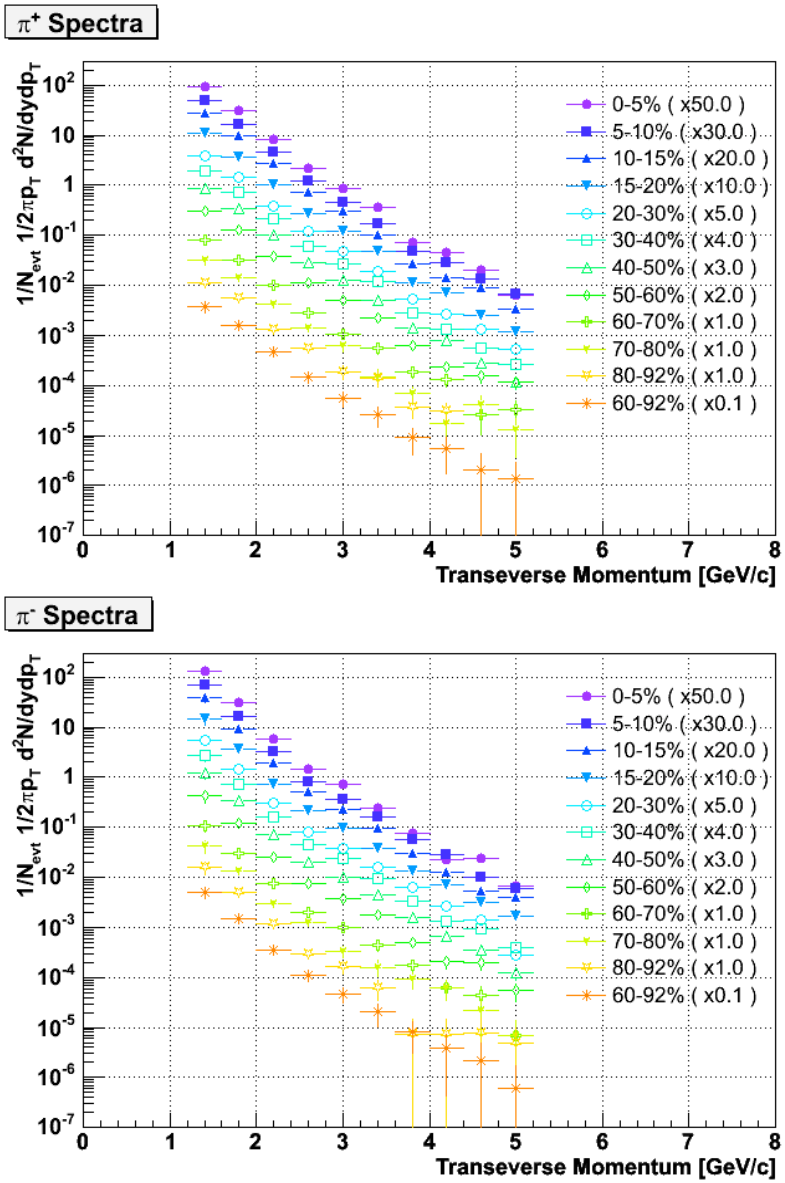
(Multi-gap Resistive Plate Chamber Prototype installed in Run5)

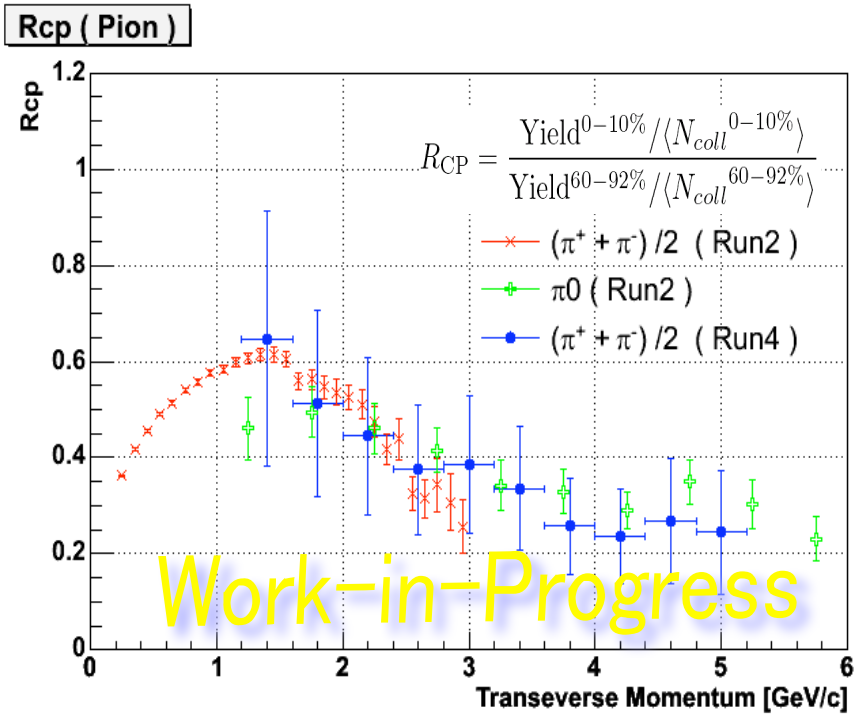






Pion p_T spectra & R_{CP} (Aerogel)

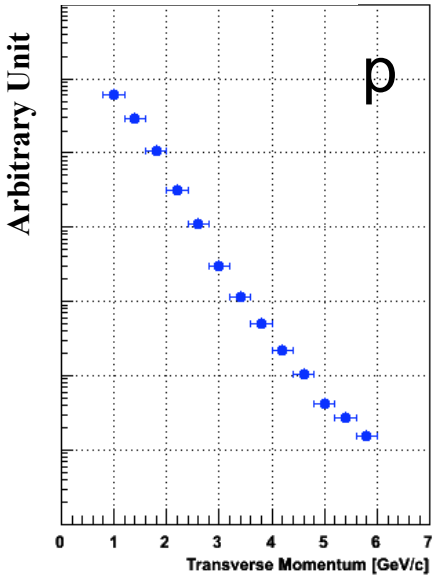


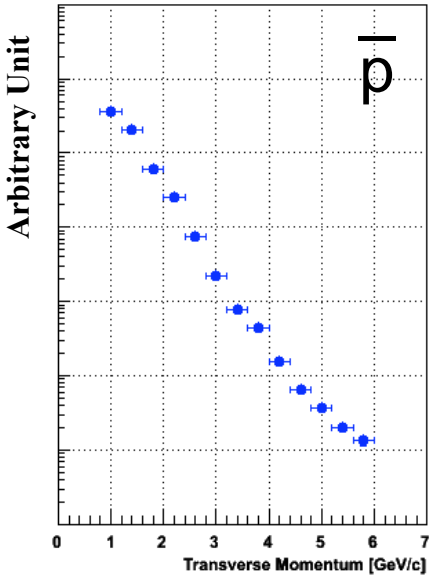


- **These are working results.**
- **Consistent with the previous results.**
- **PID p_T range extended.**

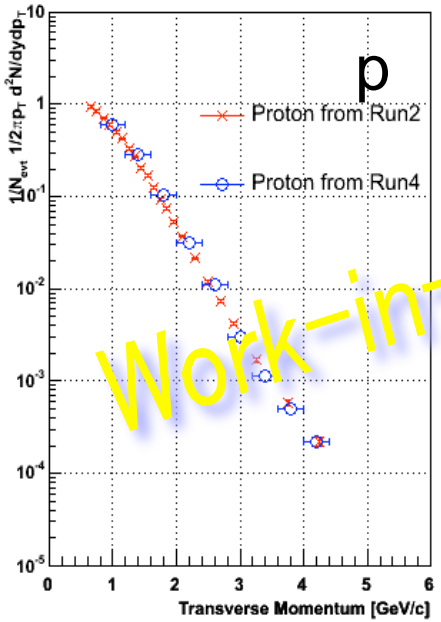
Proton p_T spectra (Aerogel)

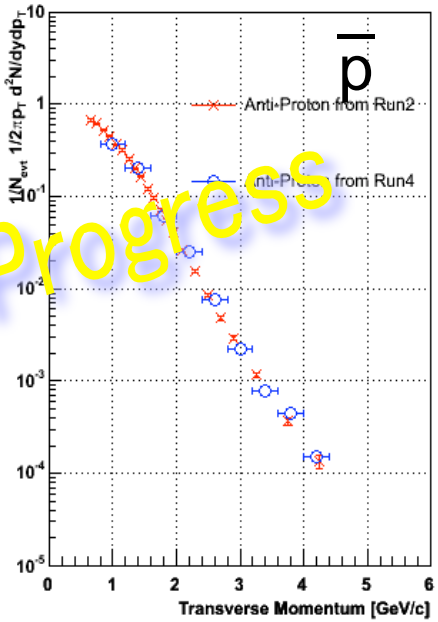
Raw yield





p_T spectra

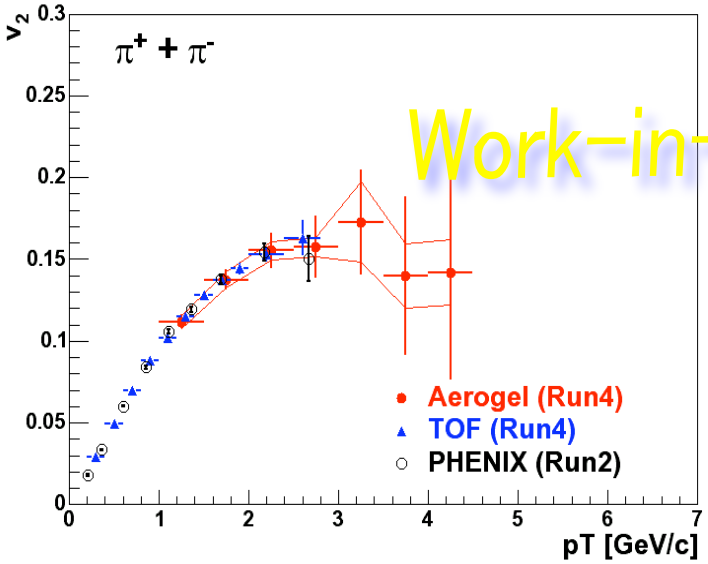


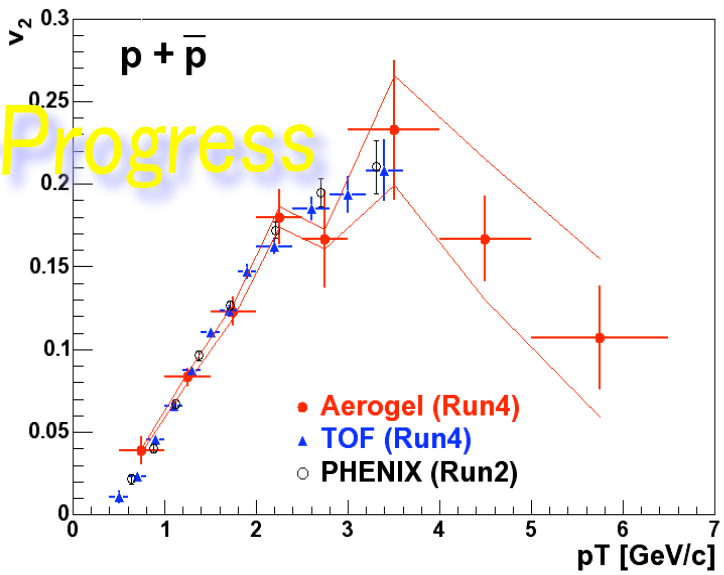


Work-in-Progress

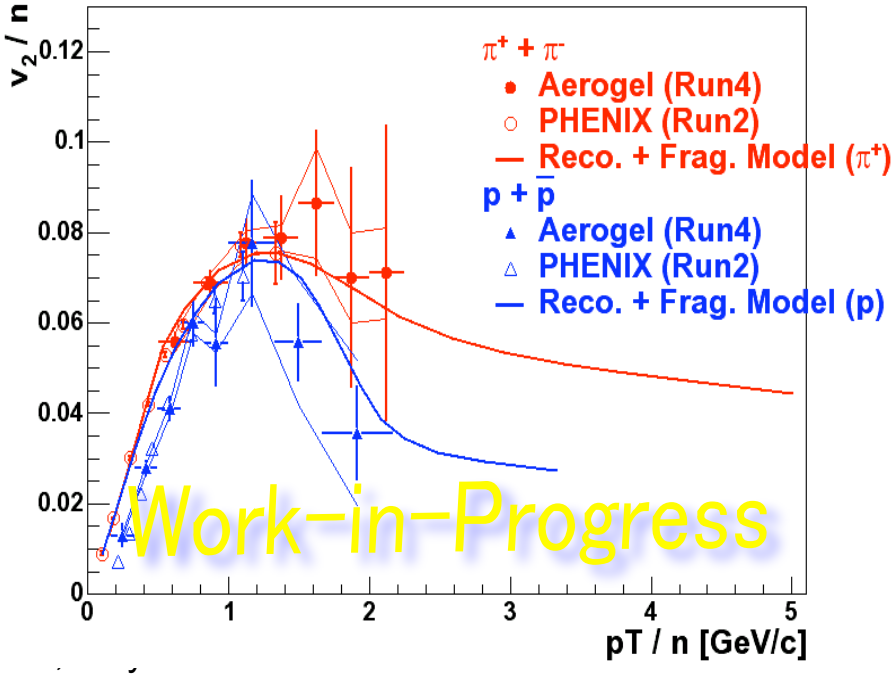
- These are working results.
- Consistent with the previous results.
- PID p_T range to be extended.

Pion/Proton v_2 (Aerogel)





Work-in-Progress



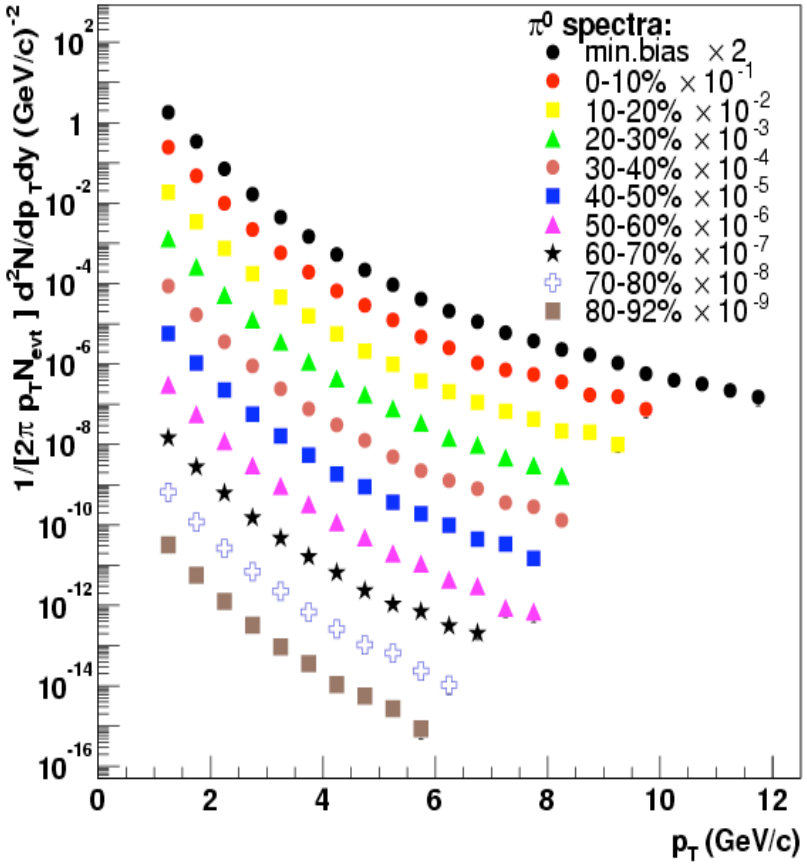
Work-in-Progress

- These are working results.
- Consistent with the previous results.
- PID p_T range to be extended.

π^0, γ - v_2
that can reach high p_T

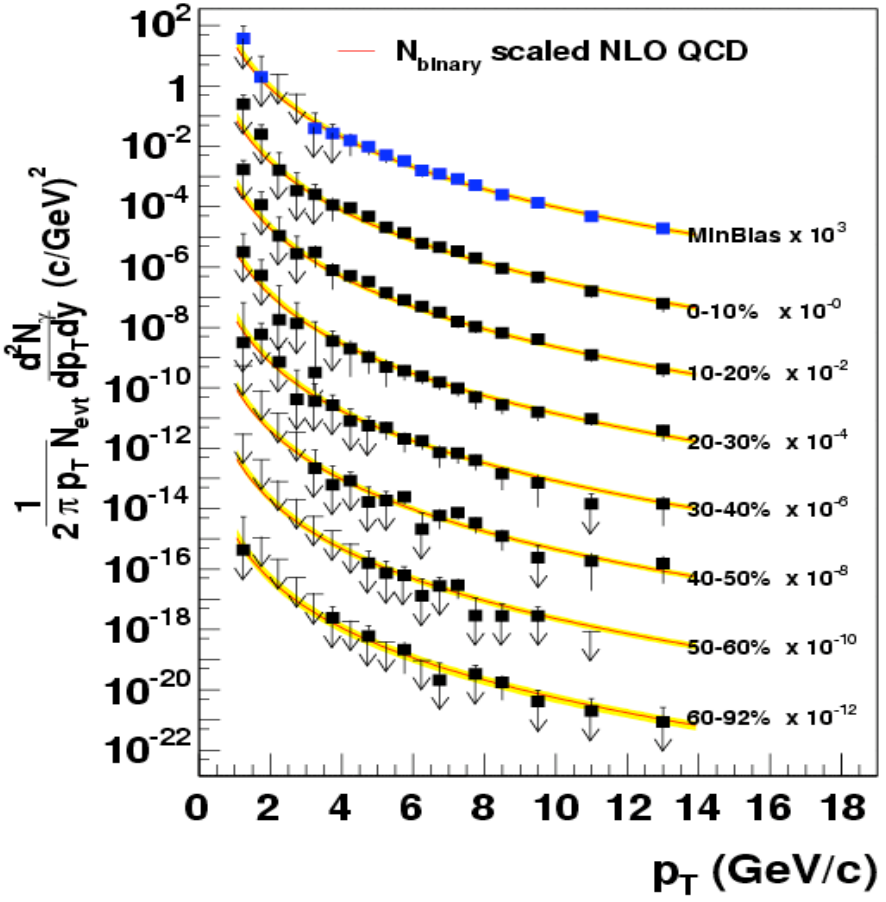
π^0, γ - p_T spectra

π^0



PHENIX, PRL 91, 072301 (2003)

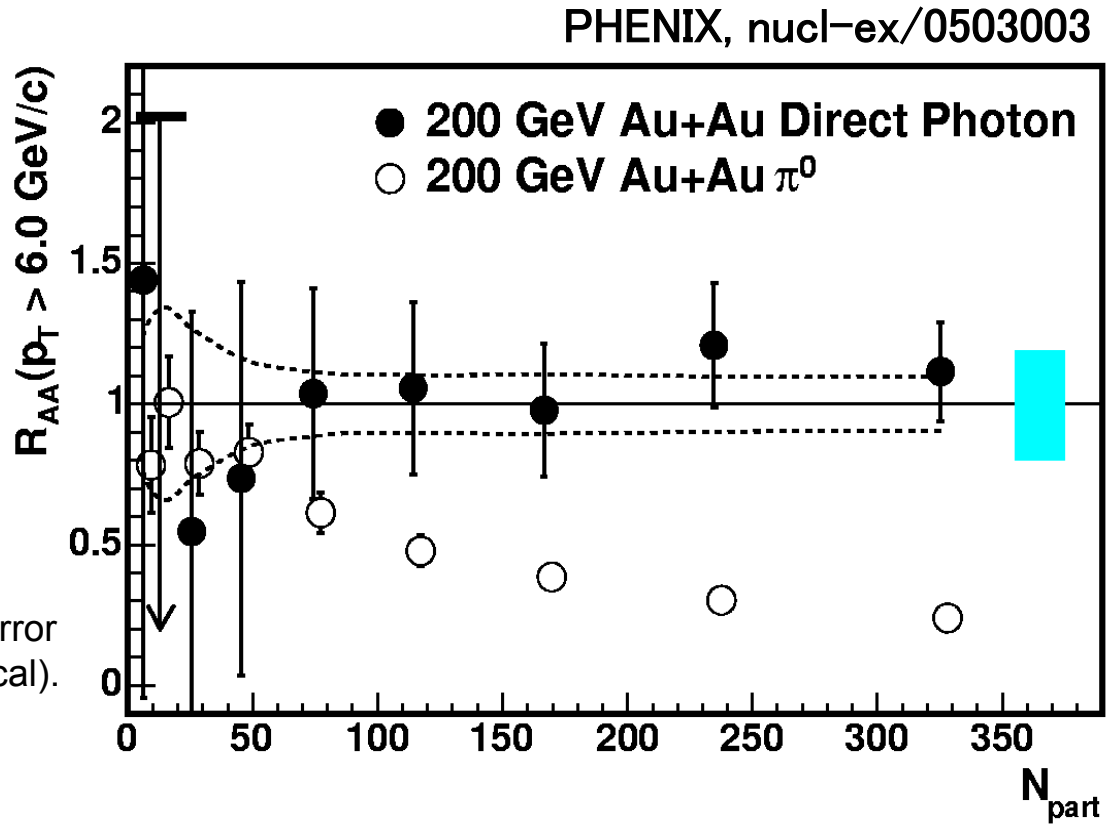
Direct Photon



PHENIX, nucl-ex/0503003

NLO QCD calculation describes all the spectra very well (from central to peripheral).

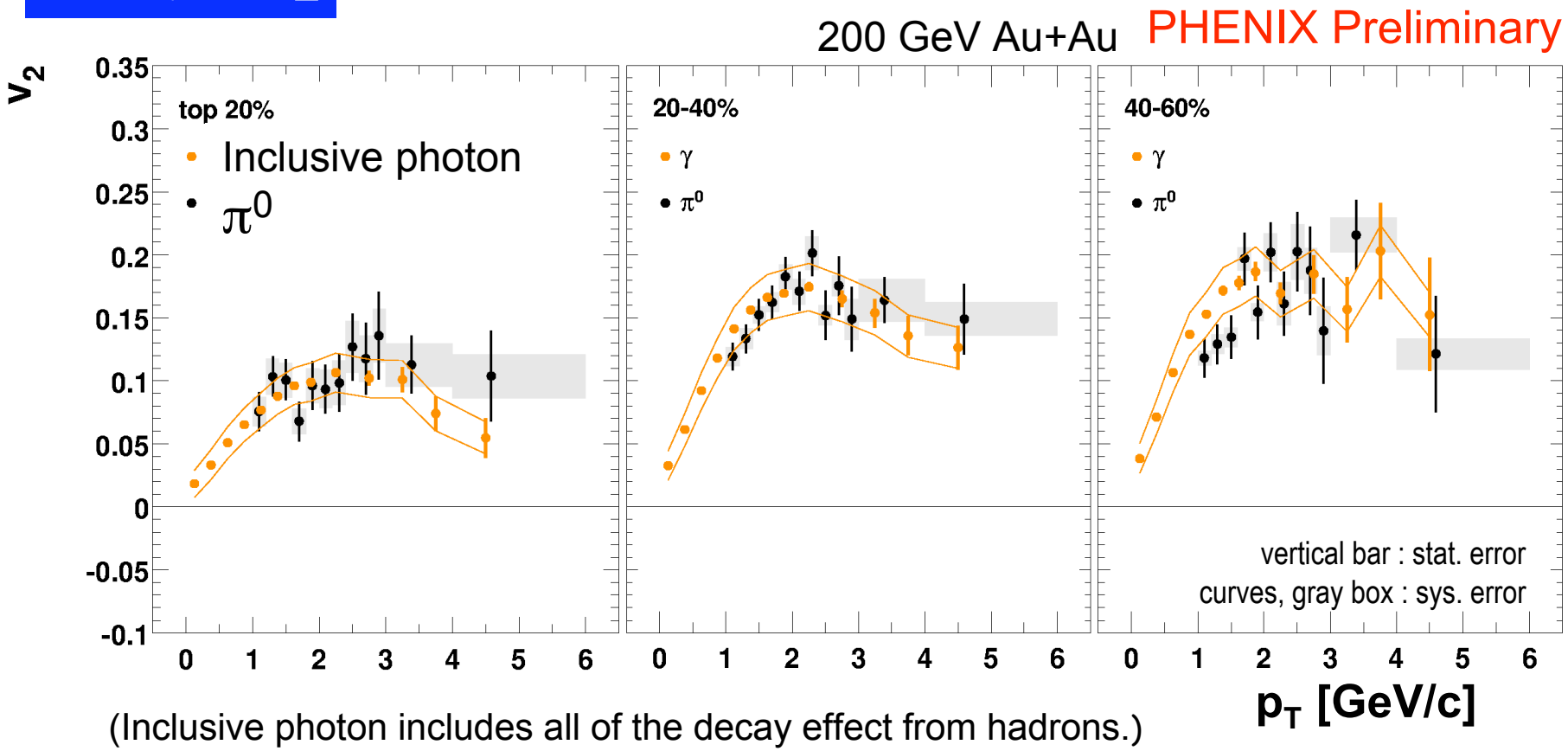
π^0, γ - R_{AA}



Error bars show total error (systematics + statistical).

- Photon R_{AA} is consistent with unity over all the centrality compared to π^0 results.
- Direct photon production in Au+Au unmodified by QCD medium.

π^0, γ - v_2



(Inclusive photon includes all of the decay effect from hadrons.)

- The difference of v2 and the g/p^0 ratio will give us a measure of direct g v_2.

Summary

- Enhanced baryon yields & v_2 (compared to meson) is consistent with quark recombination mechanisms

- Need measurements of reliable PIDed v_2 at higher p_T to understand the origin of v_2, and hadron production mechanism (baryon-meson difference):
  - + High-p_T Proton
  - + High-p_T π^0
  - (+ Direct photon)